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Fire Performance Guidelines for Shipboard Interior Finish

B. T. Lee and W. J. Parker

Center for Fire Research
National Engineering Laboratory
National Bureau of Standards
Washington, DC 20234

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Final Report

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Naval Ship Engineering Center
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FIRE PERFORMANCE GUIDELINES FOR SHIPBOARD INTERIOR FINISH

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Abstract

The present Navy fire performance requirements given in Military Standard 1623B (SHIPS) for shipboard interior finish provide a means for selecting fire safe materials. However, a recent evaluation of the Navy fire safety requirements along with an experimental berthing compartment fire study have suggested more rational design rules. New guidelines are recommended to update this standard with improved fire risk criteria.

Key words: Compartment fires; fire tests; flame spread; heat release rate; ignition; interior finish; passive fire protection; potential heat; smoke.

1. INTRODUCTION

An important element of ship design is the judicious choice of materials for the ship's interior finish and furnishings to minimize the spread of fire and smoke. Some interior finish materials may contribute significantly to fire development by the rapid spread of flames, by the generation of heat and smoke, and by serving as a fire propagation link between furnishing items within the compartment as well as between adjoining occupancies. On the other hand, there are finish materials which do not readily contribute to room fire growth and act instead as barriers to help confine the spread of the fire. Selection of such fire safe materials relies on guidelines which are based on laboratory fire test evaluation of materials.

The present Navy fire performance requirements given in MIL STD 1623B [1][1] for shipboard interior finish provide some degree of practical fire safety in Naval ship design. However, a review of the Navy fire safety requirements and recent research with compartment fires [2,3] along with the development of a flammability test for deck coverings [4,5] have suggested possible revisions to these criteria for choosing fire safe materials. This report, written at the request of the sponsor, summarizes the development of proposed new criteria and includes additional information from a recent study of shipboard fire buildup [6].

2. CURRENT PRACTICES

Fire performance requirements, presently used by the Navy for interior finish materials, are stated in MIL STD 1623B [1]. This standard considers the following three methods for evaluating the potential fire hazards of materials:

1. ASTM E 84 (tunnel test)

2. ASTM E 162 (radiant panel)

3. FED STD 501, Method 6411

These three methods are discussed briefly in the appendices A1, A2 and A3. For bulkhead and overhead sheathing, a maximum flame spread limit of 25

[1] Numbers in brackets refer to the literature references listed at the end of this paper.

by the E 84 test [7] and some limit, depending on the material, on the smoke developed by the same test are the only requirements for acceptance. In the special category of overhead acrylic light diffusing panels a maximum flame spread of 250 and a maximum smoke rating of 450 by the E 84 tunnel test are required. For deck coverings other than carpeting, Method 6411 of the Federal Test Method Standard No. 501 is the specified fire test. Surface char length and combustion time, measured with this method, are used to evaluate materials. Different sets of test criteria are given depending on the material being evaluated. For carpeting, a rating of 25 or less by the ASTM E 162 test [8] is specified for acceptance. However, there is no test requirement for the carpet to be bonded on a steel substrate as is found in practice.

3. BACKGROUND

A broad shipboard fire research program was initiated by the Navy in 1969 to help fulfill the need for (1) an improved interpretation and application of present test methods and/or (2) better laboratory test methods which could provide a meaningful correlation with the observed fire buildup in compartment fire tests. The project was structured in three phases. During the first phase a review was made of the existing specifications for shipboard construction materials and the test methods used to determine fire performance. Phase II of the program concentrated on fire test development. Phase III, focusing on the compartment fire studies and on an analytical treatment of compartment fire growth, was performed to aid in the interpretation and application of both the laboratory fire test methods recommended under phase I and the tests developed under phase II of the program.

3.1 Review of Navy Shipboard Fire Risk Criteria (Phase I)

A survey was made of the existing Navy specifications on construction materials and on the laboratory test methods used to evaluate the fire behavior of these materials [2]. The review indicated that a wide variety of tests were being used in conjunction with differing criteria to evaluate materials designated for identical usage. The same study recommended the employment of three standardized tests for surface flammability, fuel contribution and smoke generation in lieu of the existing Navy tests. Specifically, these tests were the ASTM E 162 radiant panel [8], the potential heat test [9], and the smoke density chamber [10]. All of these tests had been developed previously at the National Bureau of Standards and are briefly discussed in appendices A2, A4 and A5. It was also indicated at that time that the ignitability and the rate of heat release were important in determining the potential fire hazards of materials and that tests for these properties would be developed during phase II.

As part of the review, the deficiencies of method 6411, presently still recognized as an acceptable test under MIL STD 1623B, were also discussed. The review found that the Navy did not adopt a consistent set of test requirements, using method 6411, for different materials and that the terminology used did not allow for comparison. Furthermore, measurements with the method do not indicate the relative rates of flame spread among materials, nor do they show what levels of external heat flux are required for flame spread along deck coverings.

As interim criteria for ruling out materials having significant fire risk potential, it was recommended in the phase I report [2] that the guidelines in table 1 be used.

3.2 Development of Fire Tests (Phase II)

Following the National Bureau of Standards (NBS) survey, discussed in the preceding section, an ease-of-ignition test, which measures the exposure time required for sustained ignition by flame contact, and a heat release rate

calorimeter were developed and tested on a variety of materials [11,12] under phase II of the program. At about the same time a flooring radiant panel test [4] was also developed at NBS for measuring the critical radiant flux for flame spread on horizontally-mounted floor covering systems. These three test methods are briefly discussed in appendices A6, A7 and A8.

3.3 Development of Improved Fire Risk Criteria (Phase III)

Full size and quarter-scale compartment fires in conjunction with an approximate analytical treatment on room fire buildup were performed under phase III of the program to obtain an improved understanding of the relationship between the laboratory fire test assessment and the observed behavior of materials in actual fires [3]. In this compartment fire study, the overhead and bulkhead linings and the deck coverings were selected by the sponsor from several candidate materials for shipboard application. A description of these materials along with the compartment fire test arrangements are given in table 2. The tested variations in the interior finish included two overhead materials, three bulkhead sheathings and four deck coverings. The overhead and bulkhead materials had a fairly narrow range of flame spread and smoke generation potential. The deck coverings had a greater range but they usually did not become involved in the fire until flashover conditions were imminent. Flashover is defined here as the compartment condition where the thermal radiation level becomes high enough to spontaneously ignite light combustible materials, such as newspaper, in the lower half of the compartment. Consequently, the relationships between the laboratory fire test performance of these materials and their behavior in the actual compartment fires were difficult to establish. Nevertheless, there was sufficient information obtained upon which to provide a basis for improving the present rules for fire safe material usage.

Some results from the full size compartment fire tests are also summarized in table 2. The degree of the fire buildup in each test arrangement is indicated by the maximum interior and doorway air temperatures achieved during the fire. A summary of the results from the laboratory fire tests of the interior finish materials, used in those compartment fires, is given in tables 3, 4 and 5. Included in tables 3 and 4 are data from some follow-up laboratory tests of the compartment linings [6]. Use of some substitute materials was resorted to in the latter tests as much of the interior finish used in the compartment fire study was no longer manufactured. These substitute materials were judged to be similar to the original materials except for the differences in color, surface texture or backing construction. However, the test data in the table demonstrated that "similar" materials can have significantly different fire performance.

The fire study did not demonstrate any justification for relaxing the requirements on flame spread, potential heat, and smoke density from those recommended earlier in phase I of the project. Furthermore, the lining materials, used in these compartment fire tests, met the phase I requirements and did not provide a large increase in the fire hazard beyond that provided by the bedding itself. Therefore, it was felt that any new criteria presented should not rule out the use of these materials which have been successfully employed in the full-scale compartment tests. Nevertheless, in order to avoid serious fire problems which might arise when materials with quite different characteristics are considered in the future, additional requirements on ignitability and heat release rate should be included.

3.3.1 Flame Spread

No reason was found to alter the flame spread requirement of equal to or less than 25 on the E 162 test for the overhead and bulkhead materials. The measurement, however, must be made on the material in the same thickness and backed in the same manner as when installed. The effect of backing materials can significantly affect the specimens' behavior on the fire test. Flame

spread in a room is, however, only partially represented by the E 162 test where the flames travel downward along the specimen surface. As mentioned in another study of fire buildup in shipboard spaces [6], upward fire spread in the direction of air flow is also extremely important. Both modes of fire spread occur in compartment fires. In the initial stages of a fire, the flame spread along the interior finish is upwards from the ignition flame. The ultimate height of this flame zone, or if the flame zone exceeds the height of the overhead, its extension across the overhead, depends on some of the same factors as the flame travel distance along the E 84 tunnel [13] which is also in the direction of the air flow. The extent of this flame spread in the tunnel may, in some cases, be correlated with the rate of heat generation of the burning material [13]. Since measurement of the heat release rate is needed to fully describe the potential contribution of the material to any compartment fire, the E 84 flame spread classification for the material may then be unnecessary. Downward flame propagation as well as lateral flame travel across the bulkhead and overhead, away from this initial flame zone, may be evaluated with the E 162 test. Thus an adequate control of a material's flammability requires some limit on the rate of heat release and an upper limit of 25 on the E 162 test.

Although the same flame spread requirement may be given for the deck coverings, a more suitable acceptance criterion would be based on the ability of the material to sustain flame propagation under the thermal radiation levels anticipated on the deck surface. The flooring radiant panel test [5] measures this critical radiant flux for horizontal flame spread along the surface of a material. The E 162 test may also be used to measure critical flux values, but such measurements are made under different conditions. The data shown in table 3 for the wool carpet indicate that considerable differences can sometimes occur between the critical flux measured with the E 162 test and that obtained with the flooring radiant panel. This latter test is much more appropriate than the ASTM E 84 and ASTM E 162 methods for measuring the flammability properties of deck coverings.

The irradiance on the deck is a strong function of the air temperatures developed in the compartment. For closed bunks, i.e., units having partitions along three sides, in addition to normal ventilation conditions and no privacy curtains, the compartment air temperatures shown on table 2 did not reach 400° C. Even for bunks having opened sides or unusual air flow conditions in the space, an incipient fire would probably have difficulty in developing to the extent where compartment air temperatures would exceed 400° C for the more typical bedding arrangements. Bedding used in the berthing compartment fire tests [3] was in considerable disorder with crumpled-up bed sheets placed on the bedding to simulate clothing. This was done to assure a repeatable and sustained fire in the bunks and, at the same time, to represent a probable worst condition that could occur. The same study demonstrated that carefully made-up bedding and even bedding in considerable disarray, but without the crumpled-up sheets, led to only a low level fire environment with compartment air temperatures under 250° C. Only with the introduction of crumpled-up sheets, together with the bedding in considerable disorder, was rapid fire involvement possible. Thus it was felt that for berthing compartment fires under presently typical shipboard conditions, air temperatures would not exceed 400° C. Even at a temperature as high as 450° C the irradiance on the deck would only be about 5 kW/m^2 (0.44 $Btu/s/ft^2$). Thus, deck coverings having a critical flux equal to or higher than this value would not be expected to contribute significantly to the buildup stage of the fire.

While flame spread criteria were adequate in choosing the safe materials used in the compartment fire tests, our analysis of room fire studies conducted at Underwriters Laboratories [14] found little correlation between the flame spread ratings for the interior finish and the degree of fire buildup in the enclosed space. Their test compartment was lined with plastic board materials. A burning 9kg (20 pound) wood crib, positioned in one corner, served as the ignition source. These tests demonstrated that fires with some plastic interior finish having a 25 or lower rating on either or both of the E 84 and E 162

tests still led to flashover of the compartment. In any case flame spread ratings alone are not capable of ruling out all potentially hazardous lining materials. Therefore, it is suggested that any lining material to be used must also satisfy certain heat release and ignitability requirements.

3.3.2 Time to Ignition

Some low density foam materials which had low flame spread ratings, but performed poorly in room fires [14], also experienced self-sustained surface flaming at flame exposures of less than 60 seconds in the ease-of-ignition test. A recent study [15] indicated that materials which contributed significant fuel to the flame in the ease-of-ignition test at flame exposure times of less than 60 seconds could also contribute to an early compartment flashover. All of the overhead and bulkhead finish materials used for the compartment fires, shown in table 2, required flame exposure times greater than 60 seconds for self-sustained surface flaming and for measurable fuel contribution in the ease-of-ignition test and performed well in the compartment fires. Results for some shipboard lining materials [3,6] are included in table 3. In order to eliminate those low thermal inertia materials which ignite quickly and contribute significantly to the fire, it is suggested that flame exposure greater than 60 seconds for self-sustained flaming and for the onset of fuel contribution be set as the criterion for the ease-of-ignition.

3.3.3 Rate of Heat Release

The growth of a fire in a compartment having combustible interior finish and adequate ventilation can be described in the following sequence of events: ignition, spread of flame across the bulkheads and overhead, and rise of the compartment temperature. The rate at which a fire develops depends on the balance between the rate of heat released from the burning materials and the rate of heat dissipated through the confining boundaries of the space and by venting of the hot gases. The compartment fire experiments indicated that the temperature of the hot air layer below the ceiling is a suitable quantitative measure of the level of fire buildup in a space. When this temperature exceeds 700° C there is sufficient thermal radiation from the hot air layer and the heated upper surface to cause flashover, i.e., ignition of all combustible materials in the compartment. In general the rate of heat production needed to attain such temperatures is dependent on the size of the enclosed space, the degree and distribution of the ventilation, the location of heat sources, and the thermal properties of the interior finish. It was found in the Navy compartment fire study that a heat generation rate of roughly 72 kW/m^2 (6.3 $Btu/s/ft^2$) of deck area resulted in a temperature of 700° C in the compartment test room.

In order to effectively utilize this critical rate of heat generation for establishing heat release criteria for compartment linings, an estimate must first be made of the potential thermal contribution from the furnishings. Then the balance of the energy production needed to attain the critical air temperature in the compartment may be used to establish the limits for the rate of heat generation from the interior finish.

The rate of heat generation from furnishings depends on their distribution and degree of fire involvement. In the berthing compartment fire study [3] the fire load was representative of the present shipboard occupancy of three to four persons for each 9 m^2 (100 ft^2) of berthing area [6]. In the study only vertical fire propagation between individual berths was investigated as fire spread between adjacent furnishing items is difficult until flashover is imminent or has occurred [16].

A summary of these compartment fires [3] is given in table 2. The results indicate that fires in the bedding alone sometimes exceeded the rate of heat production required for flashover in the compartment fire tests. No regulation on interior finish materials would have prevented the occurrence of flashover

in these cases. The results in table 2 show that open bunks and curtains in front of closed bunks added considerably to the fire intensity. Fires in closed bunks, under normal ventilation conditions and without the privacy curtains, could still contribute 45% of the critical rate of heat release required for flashover, but this would allow some leeway for additional interior finish and other contents. For these safer berthing units the criteria for the heat release rate of the lining materials could be based on the concept of keeping their total heat production rate below 40 kW/m^2 (3.5 $Btu/s/ft^2$) of the deck area. This would be sufficient to prevent flashover of the compartment in most cases. The carpet did not contribute any heat until full involvement occurred in the compartment fire tests. Likewise, little fire involvement of the bulkhead surface was observed in these fires until flashover conditions were approached. While flame spread across the ceiling is relatively easy, even for low flame spread materials, downward and lateral flame propagation are not likely to occur for these materials until high thermal radiation levels are achieved in the compartment. Hence, if the flame spread criteria for the interior finish is satisfied, then the area of potential involvement could be considered to be mainly the overhead. The latter must then be restricted to a heat release rate of less than 40 kW/m^2 (3.5 $Btu/s/ft^2$) to avoid flashover of the space. The overhead materials used in the Navy berthing compartment fires would pass this criteria.

An additional margin of safety may be achieved by requiring the bulkhead lining materials to have heat release rates $\leq$ 60 kW/m^2 (5.3 $Btu/s/ft^2$). This additional requirement would permit the use of bulkhead lining materials which performed satisfactorily in the compartment fire tests while ruling out materials having high heat release rates.

The data in table 4 show the heat release rates for some shipboard interior finish exposed to the irradiance levels of 20, 40 and 60 kW/m^2. The data indicate that the rate of heat generation of a material, e.g., item 8 on table 4, can be a strong function of the radiant exposure. In the preceding paragraphs, the recommended limits on the heat release rate from materials are based on the highest one minute average rate of heat release per unit surface area as measured in the heat release rate calorimeter [12] under an irradiance level of 60 kW/m^2 (5.3 $Btu/s/ft^2$).

As the combustible fire load in berthing areas exceeds those in other living and recreational areas on board ship [6], the above fire safe criteria generated for the berthing spaces could be applied conservatively to other shipboard areas such as the wardrooms, lounges and mess halls.

3.3.4 Potential Heat

In addition to the necessity for limiting the rate of heat production and thus the intensity of the fire, there is also a need for restricting the duration of the fire. The latter requirement is intended to limit the effect of the fire on the structural integrity of the compartment components as well as to reduce the probability of fire penetration into adjoining occupancies. An approximate but commonly used relation between fire severity and fire load [17] shows that for every 12 kg/m^2 (2-1/2 lb/ft^2) increase in fire load, the fire severity, in terms of ASTM E 119 type of fire exposure, increases by 1/4 hour. This increase in fire load represents about 240 MJ/m^2 (21,000 Btu/ft^2) of deck area. A recent shipboard survey of the potential heat load in living and recreational quarters [6] showed that the typical contents in berthing spaces would lead to about 15 minutes of fire exposure, with the bedding and locker materials accounting for 11 minutes of this time. For wardrooms and lounge areas the potential fire exposure would be about 7 minutes. The compartment fire tests have indicated such exposures will melt the 0.25 cm (0.10 in) thick aluminum bunk partitions. There is further experimental evidence [18] that exposure times as short as 6 minutes could also be detrimental to 0.64 cm (1/4 in) thick aluminum plates. However, it is recognized that realistic limits must be set to allow for some choice of furnishings and interior finish

aboard ship. For this reason it is suggested that a practical limit of 11 (1000), 34 (3000) and 56 MJ/m^2 (5000 Btu/ft^2) be set for the overhead, bulkhead and deck coverings, respectively. More stringent requirements would probably add little to practical fire safety as the role of potential heat of materials in a fire depends on other parameters such as the distribution as well as the ignitability, flame spread, and rate of heat release characteristics of the materials. For a 3.0 x 3.0 m (10 x 10 ft) space having a 2.1 m (7 ft) overhead height, the compartment interior finish could then contribute another 10 minutes of fire severity. These limits would also allow the use of the materials which performed satisfactorily in the compartment fire tests. These materials are shown in table 5, along with their potential heat values.

3.3.5 Smoke Production

Criteria for limiting the generation of smoke in the compartment are difficult to establish. The burning of a relatively small quantity of certain materials could produce sufficient smoke to completely obscure visibility in the compartment, in critical spaces such as passageways, and in neighboring spaces. While the settings of visibility limits would be logical in terms of ease of egress and more effective fire fighting capabilities, they are difficult to set because they depend on the ventilation conditions and details of the structure beyond the compartment of fire origin. In spite of this there is still a need to limit the total smoke generation by materials. Due to the aforementioned difficulties, the compartment fire study was unable to improve the phase I criteria shown in table 1 for smoke control and no revision of these guidelines is recommended. As improved materials having lower smoke outputs become available, it may be advisable to consider tightening the requirements for all materials used in the berthing areas. However, more stringent limits on smoke generation should be used with caution so as not to eliminate some otherwise good materials. This is because the smoke generation potential of materials also depends on the ignitability, flame spread, and heat release properties of the materials. A material which has a low maximum specific optical density, D_m, as measured with the smoke density chamber [10], but spreads fire readily over its surface could produce more total smoke in a fire situation than another material having a high D_m value along with a low flame spread potential.

It is suggested that the smoke control requirements for interior finish remain as follows:

Location	Maximum Specific Optical Density, D_m for Flaming and Non-flaming Exposures
Overhead	≤ 150
Bulkheads	≤ 150
Deck	≤ 450

Table 5 shows that the interior finish materials which performed satisfactorily in the other laboratory fire tests also have maximum specific optical density values within these prescribed limits.

4. RECOMMENDED GUIDELINES

A critical review of the Navy fire performance requirements for interior finish [2] focused on the need for a minimal number of test methods for measuring the ignition, flame spread, rate of heat release, potential heat, and the smoke generation properties of those materials. Laboratory fire tests were also recommended at that time for evaluation of these fire properties. Subsequent compartment fire tests [3] have helped establish state-of-the-art acceptance criteria for fire safe selection of materials aboard ship based on

these laboratory tests. Observations and analysis of these compartment fire tests have resulted in an improved interpretation of fire test ratings. As a result, more rational criteria for fire risk material usage have been formulated for interior finish in Navy shipboard quarters. These design rules have been presented previously [3] and are summarized in table 6.

5. ACKNOWLEDGMENT

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6. REFERENCES

[1] Fire Performance Requirements and Approved Specifications for Interior Finish Materials and Furnishings (Naval Shipboard Use), Military Standard 1623B (SHIPS) (Nov. 14, 1975).

[2] Benjamin, I. and Gross, D., Naval shipboard fire risk criteria, final report phase I--Evaluation of fire test requirements, Nat. Bur. Stand. (U.S.), NBSIR 10159 (Jan. 26, 1970).

[3] Lee, B. T. and Parker, W. J., Naval shipboard fire risk criteria - Berthing compartment fire study and fire performance guidelines, Nat. Bur. Stand. (U.S.), NBSIR 76-1052, Final Report (Sept. 1976).

[4] Hartzell, L. G., Development of a radiant panel test for flooring materials, Nat. Bur. Stand. (U.S.), NBSIR 74-495 (May 1974).

[5] Federal Test Method Standard No. 372, Test for Critical Radiant Flux of Carpet Flooring Systems (Flooring Radiant Panel Test) (Aug. 1977).

[6] Lee, B. T. and Parker, W. J., Fire buildup in shipboard compartments - Characterization of some vulnerable spaces and the status of prediction analysis, Nat. Bur. Stand. (U.S.), NBSIR 79-1714 (May 1979).

[7] Standard Test Method for Surface Burning Characteristics of Building Materials, ASTM E 84.

[8] Standard Test Method for Surface Flammability of Materials Using a Radiant Heat Energy Source, ASTM E 162.

[9] Standard Test Method for Potential Heat of Building Materials, NFPA No. 259 (1976).

[10] Standard Test Method for Smoke Generated by Solid Materials, NFPA No. 258 (1976).

[11] Parker, W. J., The development of a test for ease of ignition by flame impingement, Nat. Bur. Stand. (U.S.), NBSIR 10495 (Feb. 11, 1972).

[12] Parker, W. J. and Long, M. E., Development of a Heat Release Rate Calorimeter at NBS, ASTM Special Technical Publication 502 (June 1972).

[13] Parker, W. J., An investigation of the fire environment in the ASTM E 84 tunnel test, Nat. Bur. Stand. (U.S.), Tech. Note 945 (Aug. 1977).

[14] Castino, G. T., et al., Flammability Studies of Cellular Plastics and Other Building Materials Used for Interior Finish, Underwriters Laboratories Inc. (1975).

[15] Lawson, J. R. and Parker, W. J., Development of an ease of ignition test using flame impingement, Nat. Bur. Stand. (U.S.), NBSIR, to be published.

[16] Fang, J. B., Measurements of the behavior of incidental fires in a compartment, Nat. Bur. Stand. (U.S.), NBSIR 75-679 (Mar. 1975).

[17] Building Materials and Structures, Nat. Bur. Stand. (U.S.), Report BMS92 (Oct. 7, 1942).

[18] Lee, B. T., Fire performance testing of bulkhead insulation systems for high strength to weight ship structures, Nat. Bur. Stand. (U.S.), NBSIR 76-1012, Final Report (Aug. 1976).

APPENDIX A. LABORATORY FIRE TESTS

A-1. ASTM E 84

The ASTM E 84 tunnel test [7] measures the flame spread performance of the specimen material relative to that of asbestos-cement board and red oak flooring under similar test conditions for a duration of 10 minutes. A 50.8 cm (20 in) wide and 7.3 m (24 ft) long specimen is horizontally-mounted in an overhead orientation in a 7.6 m (25 ft) long test chamber. The fire end of the tunnel is provided with two gas burners delivering flames upward against the surface of the test sample. An air intake port 7.6 cm (3 in) high measured from the floor level of the test chamber is provided at the fire end. The vent end is fitted to a 40.6 cm (16 in) diameter flue pipe. Changes in smoke density in the flue pipe are monitored photometrically. A thermocouple is also mounted 2.5 cm (1 in) from the sample surface, 30.5 cm (1 ft) from the vent end.

Results are given for flame spread, fuel contributed and smoke developed. These values, obtained from burning the test material, represent a comparison with those of asbestos-cement board expressed as zero and red oak flooring expressed as 100. Flame spread classification*; FSC, is determined as follows:

(1) For materials on which flame spreads 5.9 m (19-1/2 ft) in a time, t, of 5-1/2 min or less, FSC = 550/t.

(2) If the flame front spreads 5.9 m (19-1/2 ft) in more than 5-1/2 min, then FSC = 50 + 275/t.

(3) For materials on which the flame spreads less than 5.9 m (19-1/2 ft) but more than 4.1 m (13-1/2 ft), FSC = 50 + 4.6 d where d is in meters, and FSC = 50 + 1.4 d where d is in feet.

(4) When the extreme flame spread distance is 4.1 m (13-1/2 ft) or less, the classification is FSC = 16.8 d for d in meters and 5.1 d for d in feet.

The value for fuel contribution is derived by calculating the net area under the time-temperature curve from the thermocouple near the vent end for the test material and comparing this area with the net area under the curve for untreated red oak flooring.

The smoke developed during the test is determined from the time dependent increase in obscuration of a light source due to the smoke in the vent pipe. The smoke rating is derived by calculating the net area under the time-obscuration curve for the test material and comparing this area with the net area under the curve for untreated red oak flooring.

A-2. ASTM E 162

The ASTM E 162 radiant panel test [8] requires a 15 x 46 cm (6 x 18 in) specimen, facing and inclined 30 degrees to a vertically-mounted, gas-fired radiant panel. The energy output of the panel is controlled to be the same as that from a blackbody of the same dimensions operating at a temperature of 670° C (1238° F). Ignition is caused by a pilot flame just above the upper edge of the test specimen and observations are made of the progress of the flame front down the specimen surface, as well as the temperature rise of the thermocouples in a stack supported above the test specimen. The test is terminated when the flame reaches the end of the specimen or in 15 minutes,

*A new calculational method for the flame spread classification was adopted in 1976 in which the FSC is proportional to the area under the flame distance versus time curve.

whichever time is less. The flame-spread index, I_S, is computed as the product of the flame-spread factor, F_S, and the heat evolution, Q_S, or $I_S = F_S Q_S$, where

$$F_s = 1 + \frac{1}{t_3} + \frac{1}{t_6-t_3} + \frac{1}{t_9-t_6} + \frac{1}{t_{12}-t_9} + \frac{1}{t_{15}-t_{12}} \text{ and } Q_s = 0.1\Delta T/\beta$$

The symbols t_3 to t_{15} correspond to times in minutes from specimen exposure until arrival of the flame front at a position 7.6 to 38 cm (3 to 15 in), respectively, along the length of the specimen. The value of 0.1 in the relation for the heat evolution is a constant arbitrarily chosen to yield a flame-spread index of approximately 100 for red oak. The quantity ΔT is the observed maximum stack thermocouple temperature rise over that observed with an asbestos-cement board specimen, and β is the maximum stack thermocouple temperature rise for unit heat input rate to the calibration burner.

A-3. Fed. Std. 501, Method 6411

This apparatus was developed at the Naval Applied Science Laboratory (NASL), Brooklyn, approximately 25 years ago. The apparatus consists of a communicating horizontal and vertical flue constructed of 1.6 mm (1/16 in) steel sheeting lined with 3.2 mm (1/8 in) asbestos cement board with the exception of the horizontal bottom plate which is all steel. The deck covering to be tested is applied to a specimen holder made of 3.2 mm (1/8 in) mild steel plate 80.0 cm (31-1/2 in) long by 17.8 cm (7 in) wide. The holder is mounted in the horizontal flue so that hot gases can pass beneath the holder and be vented through the vertical flue. Flames and hot gases can also travel above the holder and are vented through the vertical flue. Exposure is by means of four open blast burners mounted side by side at one end of the horizontal flue, and the flames impinge both at the lower (steel) and upper (specimen) edges of the holder. The total rate of heat supply by the burners is approximately 7.0 kW (400 Btu/min) providing a moderately severe exposure.

A-4. Potential Heat Test

The potential heat test [9] provides a quantitative measure of the total heat release under typical fire exposure conditions without regard to the rate at which the heat is released.

The heat of combustion Q_r of a sample of the material, measured by an oxygen bomb calorimeter, after it has been exposed to a "standardized fire" (2 hours in a muffle furnace at 750° C (1382° F), is compared with the heat of combustion Q_m of an unexposed sample. The potential heat Q_t is given by

$$Q_t = Q_m - R\,Q_r$$

where R is the fractional weight remaining after the exposure.

Determinations may be made on simple materials, or on composite assemblies of materials from which a representative sample can be taken and pulverized into a homogeneous mixture.

A-5. Smoke Density Chamber

The smoke density chamber [10] is a 0.51 m^3 (18 ft^3) closed cabinet in which a specimen 58.1 cm^2 (three inches square) is supported vertically in a holder and is exposed to an irradiance of 25 kW/m^2 (2.2 $Btu/s/ft^2$) under one of two exposure conditions, designated as "flaming" or "non-flaming" (smoldering). For each specimen, the combustion generated smoke accumulates within the chamber and the reduction of light transmission during the test is reported in terms of the optical density of the smoke.

The method assumes the applicability of Bouger's law to the attenuation of light by smoke, and the quantity of smoke is therefore reported in terms of optical density rather than light absorption. Optical density is the single measurement most characteristic of a "quantity of smoke" with regard to visual obscuration. To take into account the optical path length, L, the volume of the chamber, V, and the specimen surface area producing smoke, A, a specific optical density is defined as $D_s = (V/LA) \log_{10} (100/T)$, where T is the percent light transmittance and the logarithmic term is the optical density.

A-6. Ease-of-Ignition Test

The ease of ignition test [15] measures the exposure times required to produce flame attachment and fuel contribution of building materials in contact with flame. Two specimens 14.0 cm (5-1/2 in) wide and 15.2 cm (6 in) high face each other 50 mm (2 in) apart. Natural gas is introduced into the gap and is ignited with a spark. The exposing flame passes between the specimen surfaces and extends about 25.4 cm (10 in) above them. The incident heat flux on the specimen surface averages 32 kW/m^2 (2.8 $Btu/s/ft^2$).

The time of flame attachment is observed visually. The time of fuel contribution is indicated by a phototube which samples the radiation from the flame.

A-7. Heat Release Rate Calorimeter

The heat release rate calorimeter [12] measures the rate of heat generation for materials exposed to radiant fluxes up to 100 kW/m^2 (8.8 $Btu/s/ft^2$) with a response time of a few seconds. A 11.4 by 15 cm (4-1/2 x 6 in) specimen, up to 2.5 cm (1 in) in thickness, is oriented vertically in front of gas-fired radiant panels lining three sides of a combustion chamber. The radiation comes from the surface of these panels whose temperatures may be varied between 627 and 1027° C (1160 and 1880° F) to produce the desired irradiance level on the sample. The edges of the specimen are shielded by an insulated holder. Air for combustion of the sample passes up through the porous floor of the chamber.

The fast time response of the calorimeter to the heat leaving the front surface of the specimen is achieved by maintaining the instrument at a constant temperature, thus overcoming the thermal inertia associated with the heating and cooling of the calorimeter walls. The constant temperature operation is accomplished with an auxiliary burner whose fuel supply is regulated by an automatic temperature controller. An increase in heat due to the burning of the specimen is then compensated by a decrease in the fuel flow rate to the burner. The measured decrease in the rate of flow of the fuel is then recorded as the rate of heat release of the specimen.

A-8. Flooring Radiant Panel

The flooring radiant panel test [5] measures the critical radiant flux for flame spread of horizontally-mounted floor covering systems. The critical radiant flux is the level of incident radiant flux on the specimen surface at the maximum flame spread distance. The specimen can be mounted over underlayment, bonded to a simulated structural floor or otherwise installed in a typical and representative way.

The radiant energy source is a premixed air-gas fueled panel inclined at 30 degrees to and directed at a horizontally-mounted 22 cm (8.7 in) by 104 cm (41 in) specimen. The radiant panel generates an energy flux distribution ranging from a maximum of 10 kW/m^2 (0.88 $Btu/s/ft^2$) to a minimum of 1 kW/m^2 (0.09 $Btu/s/ft^2$) under the low panel temperature setting of between 490 to 510° C (914 to 950° F) and from 24 to 2 kW/m^2 (2.1 to 0.18 $Btu/s/ft^2$) in the high panel temperature range of 660 to 680° C (1220 to 1256° F). Test results are reported as the critical radiant flux, W/cm^2, for failure of the flame to further propagate.

Table 1. Phase I fire test requirements

Type Material	ASTM E 162 Flame Spread Index	Potential Heat	Smoke Density Chamber Maximum Specific Optical Density
Bulkhead and Overhead Insulation	≤ 25	$\leq 2.2 \times 10^5$ kJ/m^3 (500 Btu/ft^2/in)	≤ 150
General Deck Coverings	≤ 25	$\leq 7.0 \times 10^3$ J/g (3000 Btu/lb)	≤ 450

Table 2. Compartment fire tests [3]

Test	Lining Variable	Door	Air* Supply	Bunk**	Bunk Location	Maximum+ Compartment Air Temp. (°C)	Maximum+ Doorway Air Temp. (°C)
1	Standard Set	Closed	Off	Closed	Side	191	190
2	Standard Set	Closed	On	Closed	Side	172	164
3A	Standard Set	Open	At Bunks	Closed	Side	506	545
3B	Standard Set	Open	On	Closed	Side	230	205
4A	Standard Set	Open	On	Open	Side	490	460
4B	Standard Set	Open	On	Open	Side	570	485
5	High Density Acoustical Panels on Overhead	Open	On	Closed	Side	232	225
6	Melamine Coated Panels on Bulkhead	Open	On	Closed	Side	200	236
7	Wool Carpet and Pad on Deck	Open	On	Closed	Side	244	274
8	Wool Carpet and Pad on Deck	1/2 Open	Off	Closed	Back	354	265
9***	Wool Carpet and Pad on Deck and Curtains Over Bunk Openings	1/2 Open	Off	Closed	Back	800	685
10***	Acrylic Carpet and Pad on Deck and Curtains Over Bunk Openings	1/2 Open	Off	Closed	Back	820	700
11	80% Wool-20% Phenol-Formaldehyde Carpet and Pad on Deck and Curtains Over Bunk Openings	1/2 Open	Off	Closed	Back	772	640

*Approximately 4.8 M^3/min from ceiling vent unless otherwise specified.
**Closed bunk has full partitions on both ends and along the back. Open bunk has no partitions.
***Ignition along length of bottom bunk. All other tests had localized ignitions on the bottom bunk.
+Interior and doorway air temperatures taken at 2.5 cm down from center of overhead and 2.5 cm down from lintel, respectively. Maximum interior and doorway air temperatures do not necessarily occur simultaneously in fire tests. For tests 9, 10 and 11, the maximum temperatures were taken to be the values at time of flashover.

STANDARD SET OF LININGS

Low Density Acoustical Panels on Overhead
Fibrous Glass Insulation on Two Bulkheads
Vinyl Coated Panels on Two Bulkheads
High Temp Polyamide Carpet Bonded to Steel Deck

Table 3. Summary of ignition and flame spread test results on some interior finish materials

Material	Thickness		Weight per Surface Area*		Ease of Ignition		Downward Flame Spread E-162	
					Time To Fuel Contribution	Time to Self-Sustained Flaming	Flame Spread Factor	Flame Spread Index
	(mm)	(in)	(g/cm^2)	(lb/ft^2)	(s)	(s)	F_s	I_s
Overhead								
1. Low Density Acoustical Panel No. 1**	17.8	0.70	0.21	0.42	>120	>200	4.1	7.3
2. Low Density Acoustical Panel No. 2	17.8	0.70	0.21	0.42	25	-	11.9	13.1
3. High Density Acoustical Panel No. 1**	14.0	0.55	0.56	1.15	>120	>480	3.1	5.0
4. High Density Acoustical Panel No. 2	14.0	0.55	0.56	1.15	>120	-	3.1	3.4
Bulkhead								
5. Vinyl Laminate No. 1 on 1.6 mm (0.063") Aluminum**	0.20	0.008	0.029	0.059	82	180	2.7	25.0
6. Vinyl Laminate No. 2 on 1.6 mm (0.063") Aluminum	0.20	0.008	0.029	0.059	96	-	5.1	19.7
7. Melamine Laminate No. 1 on 1.6 mm (0.063") Aluminum**	0.89	0.035	0.12	0.25	61	105	1.0	3.0
8. Melamine Laminate No. 2 on 1.6 mm (0.063") Aluminum	0.89	0.035	0.12	0.25	>120	-	1.0	5.5
9. Fibrous Glass (unpainted) No. 1**	25.4	1.0	0.16	0.33	>120	>600	4.2	8.0
10. Fibrous Glass (unpainted) No. 2	25.4	1.0	0.16	0.33	>120	-	1.0	2.0

*Excluding metal substrate.

**Materials used in the Navy compartment fires [3] are denoted by No. 1, while the No. 2 materials are the substitute materials.

Table 3. Summary of ignition and flame spread test results on some interior finish materials (cont'd)

Material	Thickness		Weight per Surface Area*		Ease of Ignition		E-162 Flame Spread			Flooring Radiant Panel
					Time to Fuel Contribution	Time to Self-Sustained Flaming	Flame Spread Factor	Flame Spread Index	Critical Heat Flux	Critical Heat Flux
	(mm)	(in)	(g/cm^2)	(lb/ft^2)	(s)	(s)	F_s	I_s	(W/cm^2)	(W/cm^2)
Deck										
11. High Temp. Polyamide Carpet on 0.64 cm (0.25") Steel	5.1	0.20	0.19	0.39	>120	420	2.9	8.3	1.9	1.8
12. Wool Carpet No. 1 on 0.64 cm (0.25") Steel**	7.1	0.28	0.22	0.45	-	>1020	2.9	20.0	2.9	-
13. Wool Carpet No. 2 on 0.64 cm (0.25") Steel	7.6	0.30	0.23	0.48	41	-	8.7	99.5	2.2	0.85
14. Vinyl Asbestos Tile on 0.64 cm (0.25") Steel	2.4	0.094	0.44	0.90	>120	>420	3.1	14.7	2.1	2.4
15. Acrylic Carpet on 0.64 cm (0.25") Steel	11.4	0.45	0.23	0.47	18	31	16.4	235.	<0.5	0.27

*Excluding metal substrate.

**Materials used in the Navy compartment fires [3] are denoted by No. 1, or are unnumbered while the No. 2 materials are the substitute materials.

Table 4. Heat release rates of some interior finish materials

Material	Radiant Exposure 2 W/cm² Maximum* One Minute Average (W/cm^2)	Radiant Exposure 4 W/cm² Maximum* One Minute Average (W/cm^2)	Radiant Exposure 6 W/cm² Maximum* One Minute Average (W/cm^2)
Overhead			
1. Low Density Acoustical Panel No. 1**			2.0
2. Low Density Acoustical Panel No. 2	0.2	1.4	1.3
3. High Density Acoustical Panel No. 1			∿0
4. High Density Acoustical Panel No. 2	0.1	0.5	0.2
Bulkhead			
5. Vinyl Laminate No. 1 on 1.6 mm (0.063") Aluminum			2.4
6. Vinyl Laminate No. 2 on 1.6 mm (0.063") Aluminum	1.9	3.3	4.1
7. Melamine Laminate No. 1 on 1.6 mm (0.063") Aluminum			5.7
8. Melamine Laminate No. 2 on 1.6 mm (0.063") Aluminum	3.7	5.5	14.4
9. Fibrous Glass No. 1 on 1.6 mm (0.063") Aluminum			2.2
10. Fibrous Glass No. 2 on 1.6 mm (0.063") Aluminum	0.5	∿0	0.7

*Error in measurement approximately $\pm$ 0.3 W/cm^2

**Materials used in the Navy compartment fires [3] are denoted by No. 1, while the No. 2 materials are the substitute materials.

Table 5. Potential heat and smoke data from compartment fire tests

Material*	Potential Heat		Smoke	
			Flaming Exposure	Non-flaming Exposure
	(MJ/m^2)	(Btu/ft^2)	(D_M)	(D_M)
Overhead				
1. Low Density Acoustical Panel	3.2	280	4	4
3. High Density Acoustical Panel	0.2	20	2	4
Bulkhead				
5. Vinyl Laminate on 1.6 mm (0.063 in) Aluminum	6.9	610	124	94
7. Melamine Laminate on 1.6 mm (0.063 in) Aluminum	23.9	2110	108	51
9. 5.1 cm (2 in) Fibrous Glass	1.1	100	18	15
Deck				
11. High Temp. Polyamide Carpet on 0.64 cm (0.25 in) Steel	38.3	3380	179	127
12. Wool Carpet on 0.64 cm (0.25 in) Steel	32.9	2900	258	133
14. Vinyl Asbestos Tile on 0.64 cm (0.25 in) Steel	22.5	1980	263	182

*Specimens without metal substrate used for potential heat measurement.

Table 6. Selection criteria for interior finish materials in Navy berthing compartments based on laboratory test methods

Location	Times to Ignition and for onset of Fuel Contribution	Flame Spread*	Critical Heat Flux for Flame Spread		Heat Release Rate		Potential Heat		Smoke
	(s)		(Btu/s/ft^2)	(W/cm^2)	(Btu/s/ft^2)	(W/cm^2)	(Btu/ft^2)	(MJ/m^2)	(D_m)**
Overhead	≥ 60	≤ 25	--	--	≤ 3.5	≤ 4	1000	11	≤ 150
Bulkhead	≥ 60	≤ 25	--	--	≤ 5.3	≤ 6	3000	34	≤ 150
Deck Covering	--	--	≥ 0.44	≥ 0.5	--	--	5000	56	≤ 450

*Flame-Spread Index from ASTM E 162. All thermoplastics which melt and drip are unacceptable.
**For flaming and non-flaming exposures.

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15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The present Navy fire performance requirements given in Military Standard 1623B (SHIPS) for shipboard interior finish provide a means for selecting fire safe materials. However, a recent evaluation of the Navy fire safety requirements along with an experimental berthing compartment fire study have suggested more rational design rules. New guidelines are recommended to update this standard with improved fire risk criteria.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Compartment fires; fire tests; flame spread; heat release rate; ignition; interior finish; passive fire protection; potential heat; smoke.

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